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Algorithms for Radio Networks

MIMO

University of Freiburg
Technical Faculty
Computer Networks and Telematics
Prof.Christian Schindelhauer

CoNe
Freiburg

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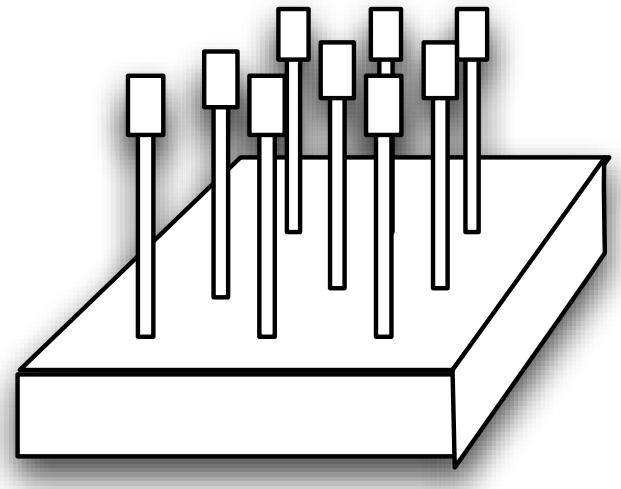
Smart Antennas

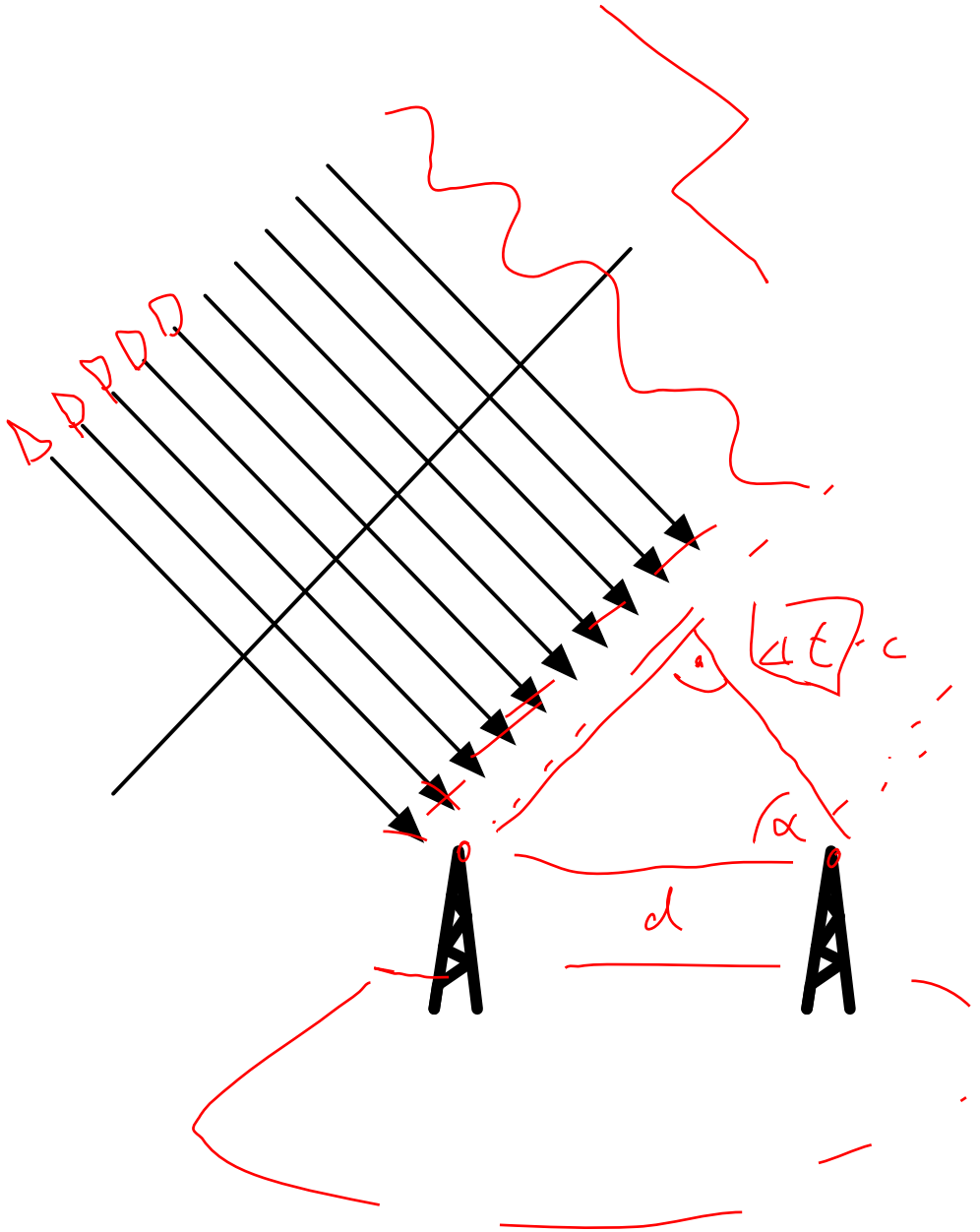
- **Alternative terms**
  - Adaptive Array Antennas
  - Multiple Input Multiple Output (MIMO)
- **Prinziple**
  - Multiple antennas are coordinated manner
    - used to improve reception or transmission of behavior
    - to allow additional features
- **Features**
  - Directional receivers
  - Directional senders
    - better path loss exponent
    - spatial multiplexing
    - MIMO communikation



DOA Estimation

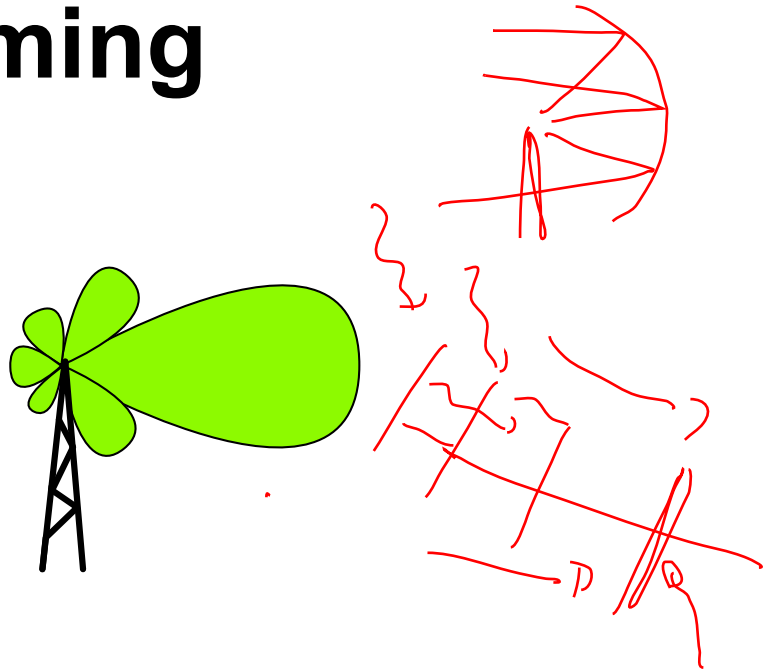
- **With two antennas, one can determine the receive direction (DOA)**
  - Paulraj, Roy, Kailath, Estimation of Signal Parameters via Rotational Invariance Techniques- ESPRIT, Nineteeth Asilomar Conference on Circuits, Systems and Computers, 1985, 83- 89
- **Idea:**
  - The signals arrive at different times to the antennas. By parallel testing of overlays can be candidates for the angle of incidence findenn

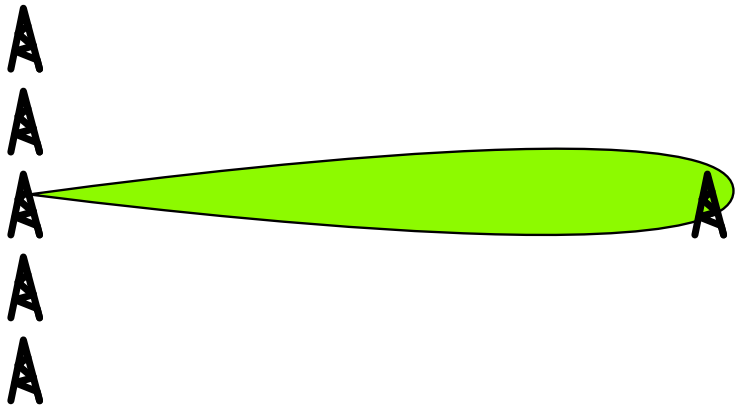
$$\sin\alpha = \frac{\Delta t \cdot c}{d}$$

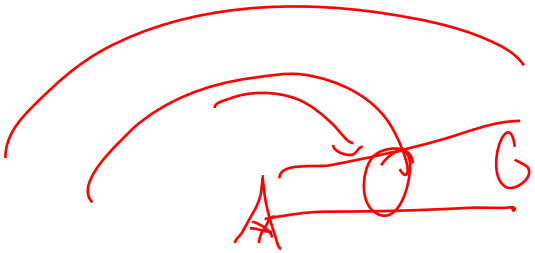


Beam forming

- **Simulation of receiving or transmitting antenna behavior of any of Smart Antennas**
- **Active**
  - By suitably chosen time shift, receipt of signals at the antennas will transmit the desired direction preference
    - Other directions only increase only background noise
  - Applications: radar, mobile communications, MIMO
- **Passive**
  - As with the DOA-detection, the signals are delayed and superimposed
  - Applications: Microphones, MIMO

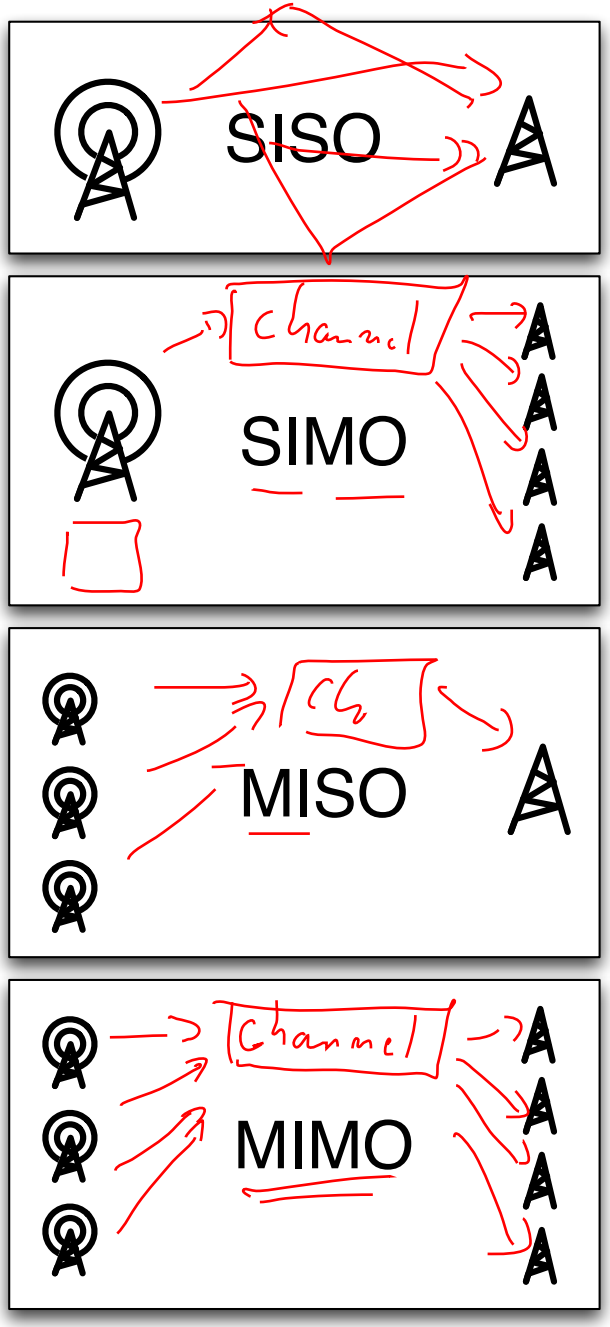






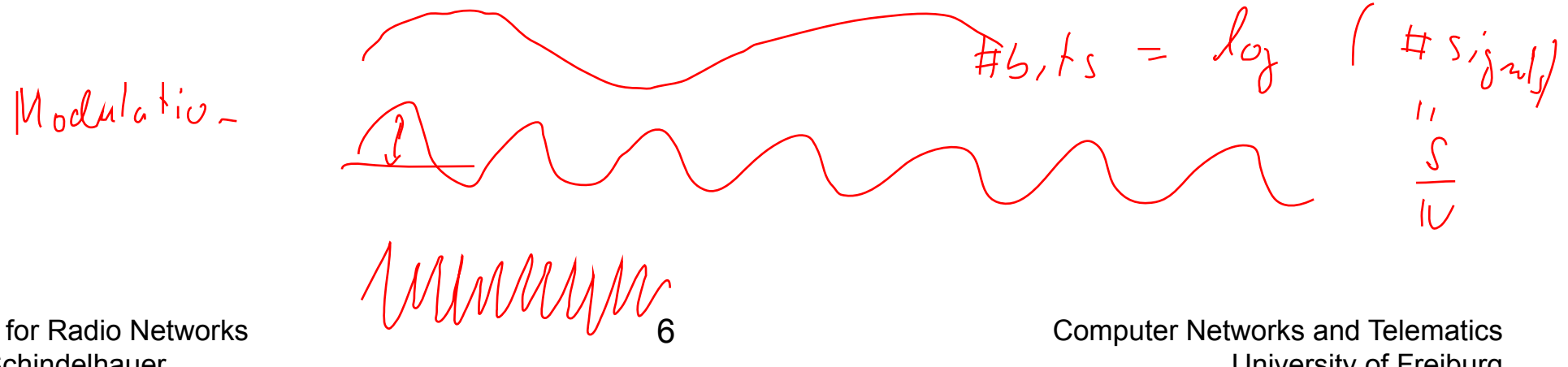
Smart Antennas Combinations

- **SISO (Single Input Single Output)**
  - Classic radio model
- **SIMO (Single Input Multiple Output)**
  - Classical transmitter with an antenna
  - Antenna array at the receiver
  - Different channels can be received in parallel from different angles
- **MISO (Multiple Input Single Output)**
  - Antenna array as a transmitter
  - Individual recipients (groups) can be individually reached
- **MIMO (Multiple Input Multiple Output)**
  - Directed (and parallel) communication between the transmitter and receiver possible
  - Efficient utilization of the medium



Motivation for MIMO

- **Increase of SINR by**
  - more sender antennas
  - more receiver antennas
- **Multipaths**
  - are used for increasing the channel capacity
- **Capacity**
  - grows with the complexity of the environment
  - with the number of senders and receivers



MIMO Free Space Model

- **The message m is modulated as x(t) over a carrier**
  - i.e. $s(t) = x(t)\, e^{j2\pi ft}$
- **Electric field is described by the signal**
  - ~ force on charged particles
  - adds up (superposition)
  - decreases proportional to the distance
- **Power is proportional to the square of the electric field**

$$\mathrm{SINR} = \frac{\left| \sum_{\text{sender } i} \sum_{\text{receiver } k} s_i \cdot \frac{e^{j|u_i - v_k|}}{|u_i - v_k|} \cdot g_k \right|^2}{\sum_{\text{receiver } k} |g_k|^2 \left(N + \sum_{\text{interference } i} \frac{P_i'}{|w_i - v_k|^2} \right)}$$

MIMO Free-Space SINR

amplitude & phase modification by

sender channel receiver

$$\mathrm{SINR} = \frac{\left| \sum_{\text{sender } i} \sum_{\text{receiver } k} s_i \cdot \frac{e^{j|u_i - v_k|}}{|u_i - v_k|} \cdot g_k \right|^2}{\sum_{\text{receiver } k} |g_k|^2 \left(N + \sum_{\text{interference } i} \frac{P'_i}{|w_i - v_k|^2} \right)}$$

channel matrix

$$\mathrm{SINR} = \frac{|s \cdot H \cdot g|^2}{N' + I}$$

MIMO-SINR = SINR

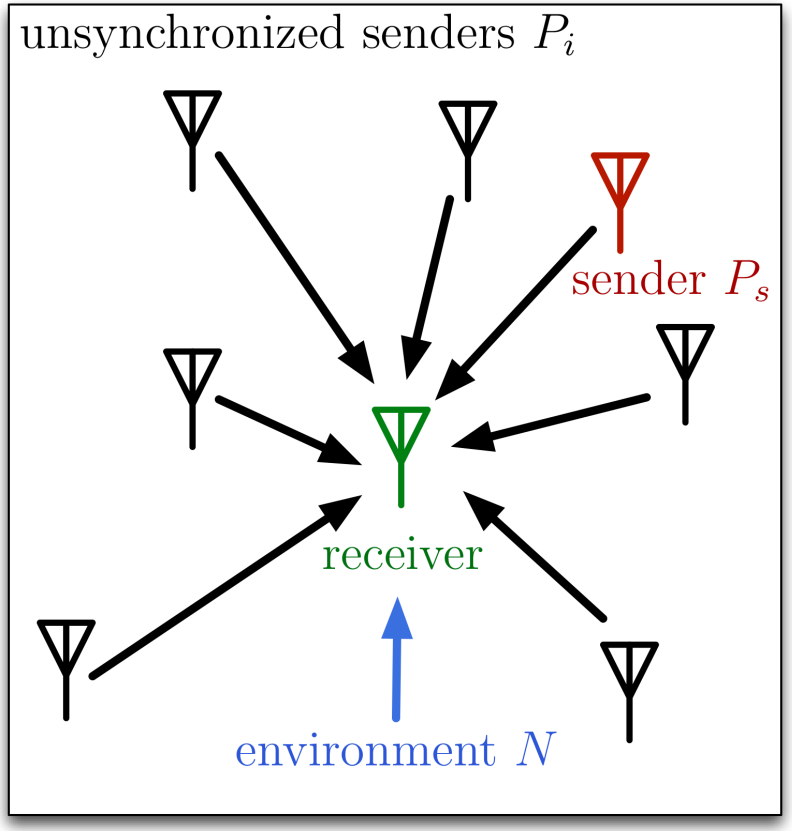
- SINR model adds the power of interferers

$$\frac{P_s}{N + \sum_{i \neq s} P_i} \geq \beta$$

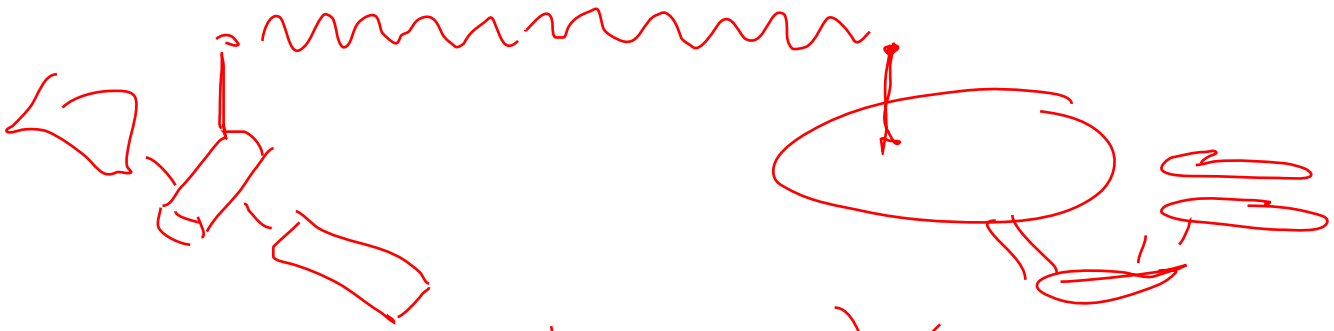
- Superposition of principle (only) for electrical fields

$$P = \left(\sum_i E_i \right)^2$$

- Independent interferences



$$\mathbb{E}\left[\sum_{i \neq s} E_i\right]^2 = \mathbb{E}\left[\sum_{i \neq s} |E_i|^2\right] = \mathbb{E}\left[\sum_{i \neq s} P_i\right]$$



$$= e^{ix} = 1 + \cancel{x} - \frac{x^2}{2} - \cancel{\frac{1}{3!}} + \frac{x^4}{4!} \cdots$$

$$i = \sqrt{-1}$$

$$\cos x = \mathrm{Re}\left(\boxed{e^{i \cdot x}}\right)$$

$$e^x = 1 + x + \frac{x^2}{2} + \frac{x^3}{3!} \cdots$$

$$\cos x = 1 - \frac{x^2}{2} + \frac{x^4}{4!} - \frac{x^6}{6!} \cdots$$